U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TCREC TECHNICAL REPORT 62-99

RECIRCULATION PRINCIPLE FOR GROUND EFFECT MACHINES
MAN-CARRYING TEST VEHICLE AND COMPONENT TESTING

Task 9R99-01-005-04

Contract DA 44-177-TC-710

February 1963

prepared by:

MARTIN COMPANY
Orlando, Florida

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U. S. ARMY TRANSPORTATION RESEARCH COMMAND
Fort Eustis, Virginia

This report presents the design and construction details of an air cushion vehicle using the recirculation principle. The vehicle was intended purely as an experimental research craft without application to any Army mission. Therefore, no specifications for this class of vehicle should be inferred from the design.

A test program, to determine the performance, stability, control, and operational characteristics of the machine, is in progress and will be the subject of future reports.

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CONTRACT DA 44-177-TC-710

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RECIRCULATION PRINCIPLE FOR GROUND EFFECT MACHINES

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ORLANDO AEROSPACE DIVISION

for

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FOREWORD

This report is submitted as an interim report in full compliance with the requirements of Clause 3, Paragraph (e) of Contract DA 44-177-TC-710 as amended by Modifications Nos. 1 and 5 thereof.

The report presents the design considerations and construction techniques which resulted in the fabrication of a man-carrying test vehicle using recirculating ejectors for lift. The work presented herein was conducted over a 9 month period, from July 1961 to April 1962.

Mr. J. Butsko compiled the information from the individual contributions of R. Reiland, B. Robinson, and C. Middlebrooks. This report has been reviewed and approved by Mr. K. Cossairt, GEM Project Engineer.

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1.0 SUMMARY

This report describes the design and construction of a research vehicle utilizing recirculating ejectors for the lift system. The design, fabrication and installation of the power plant, recirculating ejector system, primary structure, pneumatic duct system, and control system are discussed in detail and an overall description of the vehicle is presented.

A hover height of one foot and a weight/power ratio of 8 to 10 were the basic performance objectives which governed the design philosophies and considerations. The initial purpose of the man-carrying test vehicle is to evaluate the hovering performance, stability and control of a vehicle using annular recirculation.

2.0 INTRODUCTION

The Martin Company began its effort in the field of GEM research as early as 1958. Extensive experimental and analytical work was done at the Orlando Division on flow phenomena, performance, and static stability of conventional annular jet configurations. Martin Marietta began studying the general concept of recirculation in 1959, and the development of the recirculating ejector principle was the result of this effort.

A program to substantiate and extend the existing theoretical analysis of Reference 1, and to prove two-dimensionally, the feasibility of the recirculating ejector concept was conducted over a one year span, from January 1961 to January 1962. The program was sponsored by TRECOM under Contract DA 44-177-TC-710. The results of the study substantiated the feasibility of the Ejectijet principle. The logical extension of the study was the construction of a test vehicle which would demonstrate the application of recirculating ejectors as a lift system for GEM's. The design and construction of a man-carrying test vehicle (MCTV), which initially would evaluate the hovering performance, stability, and control effectiveness of an Ejectijet GEM, is described in this report.

3.0 DESIGN ANALYSIS

3.1 PRELIMINARY DESIGN CONSIDERATIONS

The scope and extent of the design program was established initially by determining the operating characteristics and size of the vehicle. To demonstrate basic feasibility and performance of an Ejectijet vehicle, it was decided that the MCTV should primarily be a hovering vehicle. A basic performance objective was established by the selection of the design hover height of one foot. A second performance objective was established by the selection of a weight-to-power ratio between 8 and 10 pounds per horsepower. These values were considered reasonable for the initial Ejectijet test vehicle. It is subsequently shown that these values of weight-to-power ratio exerted a strong influence on vehicle weight, engine selection, and ejector design.

The overall size of the MCTV was determined by the performance objectives of the program. Since the MCTV was to be an experimental vehicle, the payload capability was restricted to the weight of the operator. The total lift required was dependent on the weight of the vehicle subsystems and the weight of the primary structure. The planform size and shape of the primary structure were dictated by the base pressure and jet curtain perimeter available from the lift system as design height.

The design of the MCTV was divided into five basic areas:

1. Propulsion system
2. Primary platform structure
3. Recirculating ejector system
4. Pneumatic ducting system
5. Control system

These design areas, although related by the requirements of each system, required individual analysis and investigation to produce a prototype Ejectijet vehicle.

3.2 DESIGN ANALYSIS OF POWER PLANT

3.2.1 Selection of Power Plant, Limitations, and Future Requirements

During the preliminary design of the MCTV, the AiResearch GTC-85 gas turbine compressor was chosen for the power plant. It was chosen mainly because of its availability (GFE), ease of installation, and ease of servicing. One engine in new condition produces 160 pneumatic horsepower at standard day condition and weighs 230 pounds. Preliminary weight estimates indicated that the vehicle would weigh approximately 2,500 pounds, therefore two GTC-85 turbo-compressors were required to maintain the established weight/power ratio of 8 to 10. Also, the ejector design analysis showed that two of these engines would be required to produce the necessary jet curtain strength.

Subsequent calibration tests (Section 3.2.2) of the procured engines (which had the lowest performance rating of the series requested) indicated that pneumatic performance was marginal at ambient temperatures greater than 75°F. However, at this stage the design of the ejectors and header-nozzle combinations had been "frozen" and tooling initiated, hence an engine change was out of the question.

Two-dimensional recirculating ejector tests conducted as the MCTV was nearing completion showed that significant gains in vehicle performance could be obtained. However, this could only be accomplished by utilizing engine-compressor units capable of delivering significantly different quantities of compressed air at a different pressure than the AiResearch GTC-85 series are capable of delivering.

The experience gained from the present MCTV power plant installation combined with the results of the latest propulsion studies and two-dimensional recirculating ejector tests are summarized in Table 1. The first section of this table shows the performance of the present configuration and the performance that could be expected with relatively minor modifications. No assumption is made as to whether an engine-compressor unit is available to provide the primary air in the quantities or pressors indicated.

Section II of Table 1 is a survey of engines and the related vehicle performance. A comparison of the two sections illustrates that there are no units available which deliver air in the desired quantities and pressures indicated by line I c). Comparing line I a) with line I c) it is seen that the lift at a 12 inch height can be increased from 1,800 pounds to 3,000 pounds while the installed horsepower is slightly reduced. This is a result of increasing the ejector efficiency by increasing the primary mass flow and reducing the primary pressure.

3.2.2 Description of Power Plant

The MCTV is powered by two AiResearch model GTC-85-24 gas turbine auxilary power units. These units are normally used by both the military and commercial airlines for starting turboprop and turbojet aircraft engines.

The model GTC-85-24 gas turbine auxilary power unit is basically a self-contained gas turbine-driven air compressor. Compressed air is obtained from the unit by bleeding from the second stage of a two-stage centrifugal compressor, which also supplies air to the turbine. Turbine inlet air from the compressor is directed through the outlet plenum of the turbine housing into a turbine combustion chamber, and is then directed into the radial-inflow-type turbine wheel. All power produced by the turbine, except for the demands of lubrication, fuel pumping, control system components, the unit generator, and other integral accessories, is absorbed by the compressor. The unit requires an external source of fuel and oil for all operations and an external source of electrical energy for starting.

3.2.3 Performance Rating

With NACA standard sea level day conditions external to the air inlet and exhaust duct and with the use of the turbine exhaust gas diffusing duct shown on the compressor outline drawing, or its equivalent, each unit is capable of the following continuous output rating.

(1) Compressor bleed-air flow ~ $117 {}^{+0}_{-3}$ lb/min

(2) Compressor bleed-air total temperature ~ 408 ± 35°F

(3) Compressor bleed-air total pressure ~ 103.8 in. hg abs (minimum) (51 psia)

Figure 1 presents the flow calibration curves for these engines. Other general specifications are:

(1) Fuel consumption ~ 230 #/hr @ 100 percent load and 60°F

(2) Oil consumption ~ 0.25 lb/hr maximum

(3) Exhaust temperature (maximum) ~ 1200°F

(4) Fuel type ~ MIL-F-5624, Grades JP-3 and JP-4

(5) Oil type ~ MIL-O-6081, Grade 1010

(6) Weight dry ~ 230 lbs

3.2.4 Forward Propulsion

Nominal forward speeds will be accomplished through utilizing the residual thrust of the exhaust. Each engine is equipped with a modulation valve that allows 100 percent thrust variation. With the valve fully open, each engine produces approximately 40 pounds of static thrust with zero load. At 100 percent pneumatic load, the thrust level drops approximately 20 percent. Precise thrust values as a function of percent pneumatic load may be obtained by referring to the thrust calibration curves of Figure 2.

3.3 DESIGN ANALYSIS OF PRIMARY STRUCTURE

The structural design philosophy of the primary structure resulted directly from the basic objective of the program. Since the MCTV was designed primarily to demonstrate the hovering performance of a recirculation system, the primary structure was required to support the recirculating ejectors at the periphery and to support the primary pneumatic ducting, power plants, control system and associated hardware while fulfilling the structural design criteria in hover.

The following discussion presents a brief description of the facts and assumptions used in the design of the primary structure. The discussion is divided into four parts:

1 Structural design criteria

2 Structural design philosophy

3 Structural description

4 Structural analysis

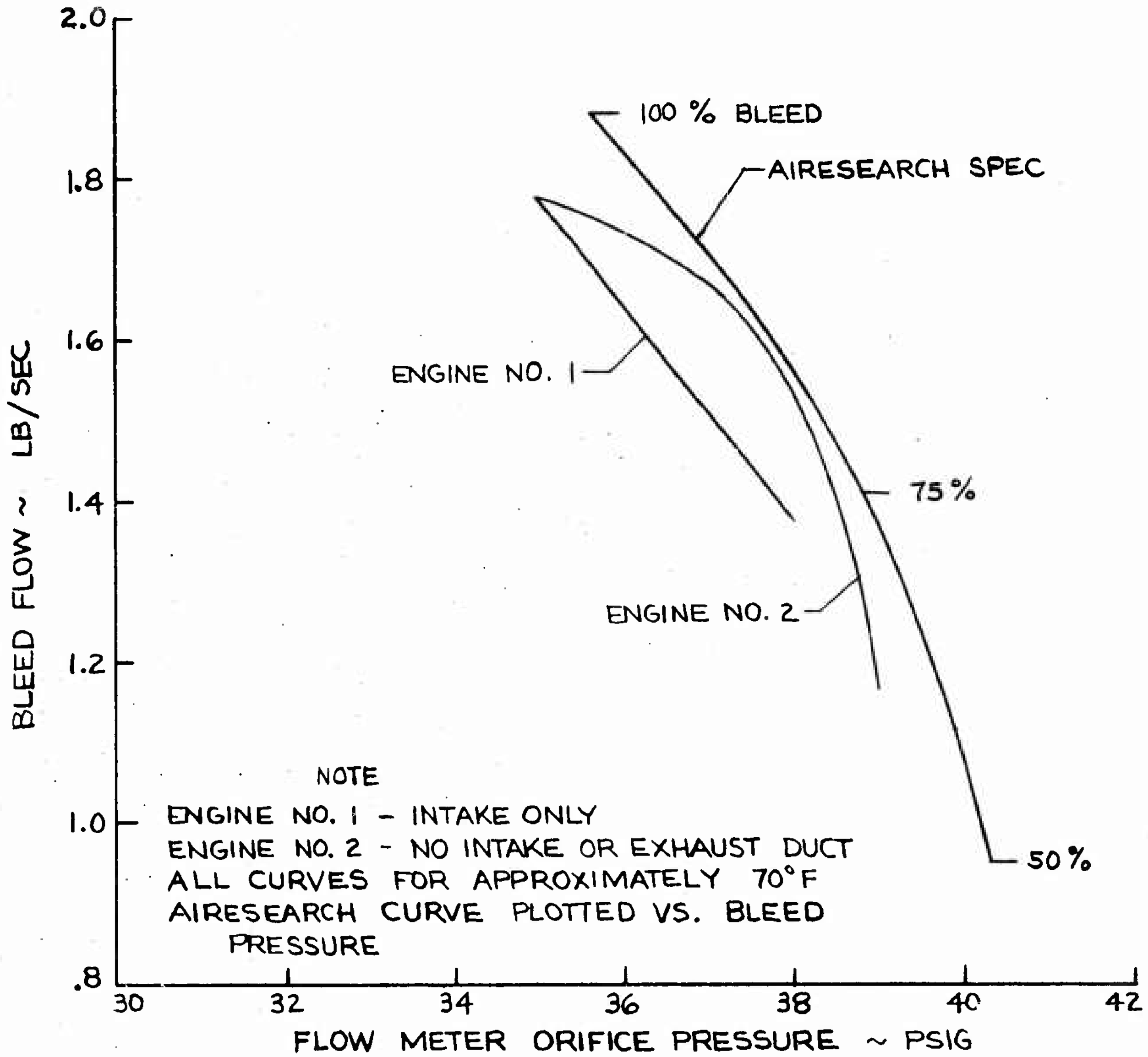


FIGURE 1 ENGINE-COMPRESSOR BLEED FLOW CALIBRATION

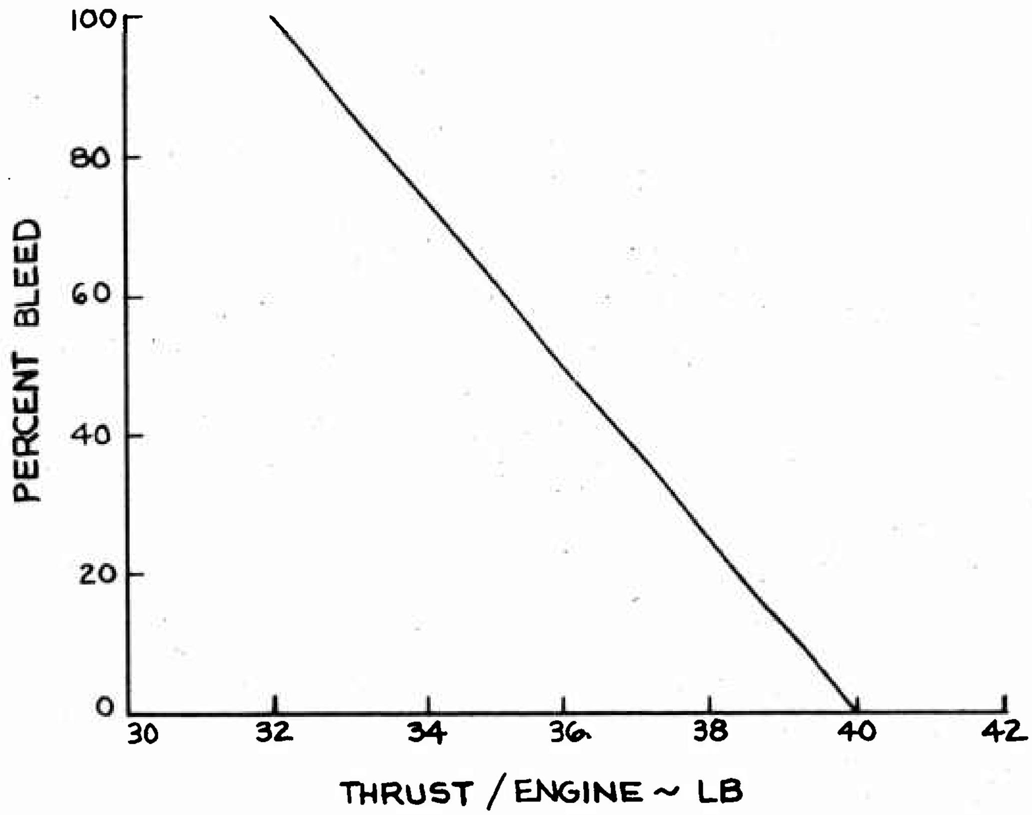


FIGURE 2 ENGINE EXHAUST THRUST CALIBRATION

3.3.1 Structural Design Criteria

In order to design the MCTV primary structure, it was necessary to select design criteria which would satisfy the vehicle performance requirements and at the same time provide a high degree of safety and reliability.

The performance criteria for the MCTV required a primary structure of size and strength sufficient for hover at a height of 12 inches with a gross weight not exceeding 2,500 pounds. However, further design considerations were added since forward flight demonstration would be a natural extension of the initial MCTV development program. Design of the structure primarily for hovering but with forward flight capabilities required a restriction on anticipated forward flight operations. It was established that the MCTV would be operated only over smooth terrain or unobstructed water surfaces. This limitation eliminated the necessity of designing for collision with stumps, rocks, or similar obstacles. It was concluded that such design requirements would needlessly penalize the vehicle in both weight and cost.

The principal structural design conditions for the primary structure designed the primary bending and shear members. This condition consisted of a 4 g acceleration due to impact resulting from a complete power failure at a hover height of 24 inches. This acceleration was based upon an excursion distance of 3 inches as a result of tire deflection, structural deflection and ground or water surface. The impact was assumed reduced by 50 percent due to the cushioning resulting from the time-delay of base pressure loss.

A safety factor of 1.50 was applied to this load in order that no permanent deformation should occur at 4 g's and no failure should occur at 6 g's. Maximum ultimate bending moment at the vehicle center-of-gravity is approximately 254,000 in-lbs. Figure 3 illustrates the structural load imparted by a 1 g landing.

Another structural design condition was established which produced maximum torsional moments allowable on the basic structure. Such a condition could be produced in a variety of ways such as an off-center landing, jacking loads on one corner, and control forces produced by the ejectors.

3.3.2 Structural Design Philosophy

Several decisions were made early in the structural design program which produced definite philosophy and requirements concerning the structural arrangement and fabrication technique to be used. These decisions were obviously interrelated.

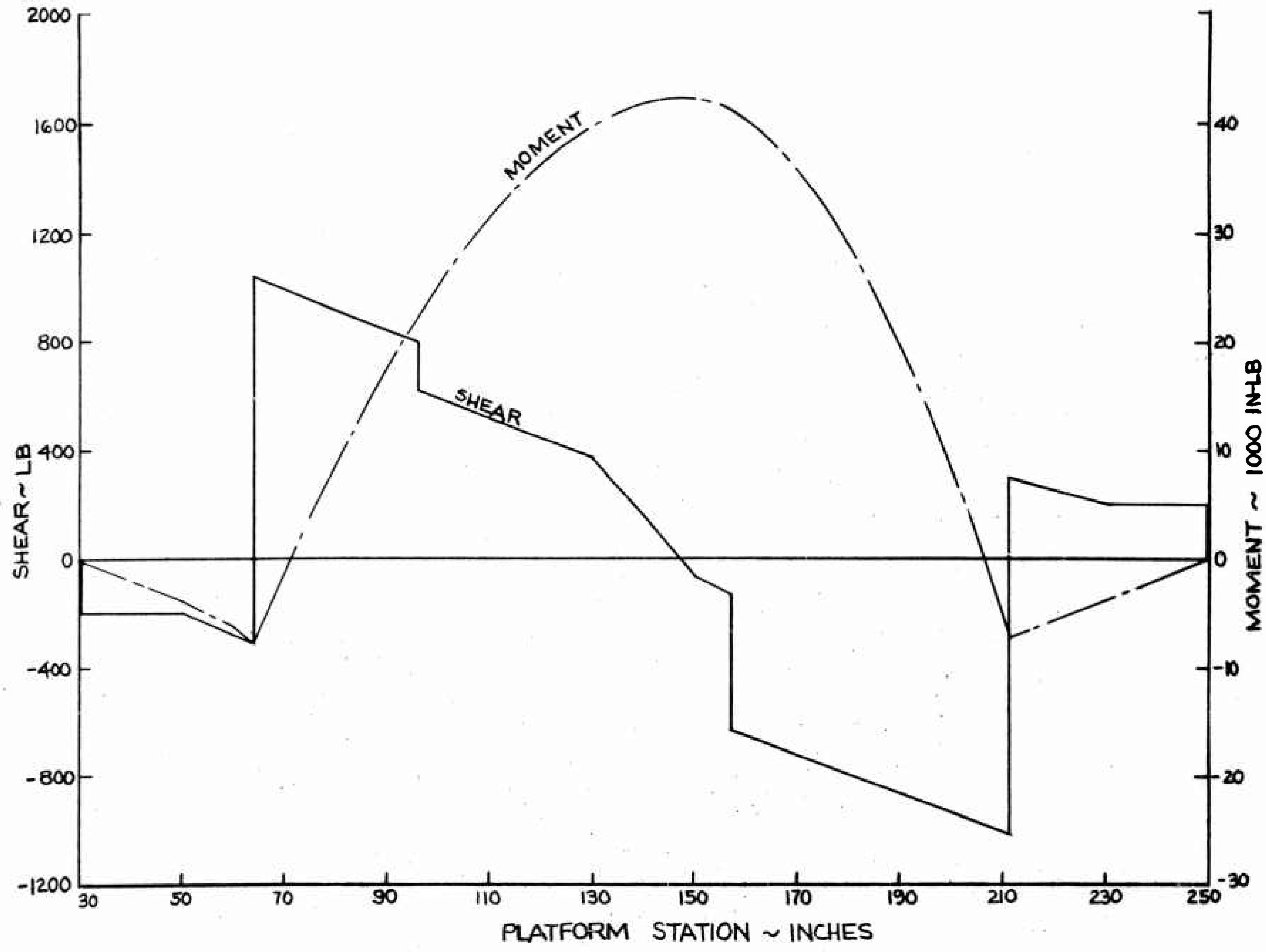


FIGURE 3 PLATFORM STRUCTURAL LOAD DIAGRAM FOR SYMMETRICAL 1-G LANDING

Some of the most significant design philosophies established were:

1. Fabricate single article with minimum expense using informal shop/engineering relationship.

2. Must be built with crude tooling requiring no long lead times. No exotic fabrication methods or materials permitted.

3. Floatation must be provided for overwater operation.

4. Must have ability to make modifications simply and quickly.

5. Must have convenient access to systems and equipment for modification during experimental flight test program.

6. Must have rigidity to minimize distortion of the platform due to movement and torques produced by the control system.

Ease of fabrication was the principle reason for selection of the torque-box. All parts are simple straight line elements with no curved surfaces or similar complications. This type of structure permits very simple jigs and fixtures since only flat sheets and right angle joints are involved. Another valuable quality is the convenience of being able to make modifications to this type of structure. A significant application of this advantage was illustrated when the addition of corner ejectors and marginal engine performance necessitated an increase in size of the base platform after it had been built. This was accomplished by simply adding another "cell" on each side of the original platform.

The torque-box structure was selected secondarily for its excellent stiffness qualities which are provided at minimum weight. Rigidity was considered of prime importance in minimizing deflection problems associated with loads from bleed air ducts, engines, control system and ejectors.

The primary structure was designed so that the addition of brackets or mounts could be accomplished conveniently by picking up fasteners at the nearest structural member since the vehicle is essentially a grid of beams, ribs and stringers.

3.3.3 Structural Description

The base platform structure supports the majority of the vehicle equipment and payload in addition to transmitting the base pressure to the entire vehicle. The dimensions of the platform are 144 inches x 180 inches with beams running the long dimension and ribs running the width. This grid of beams and ribs is covered by skins to form a torque-box. Figure 4 illustrates the platform construction.

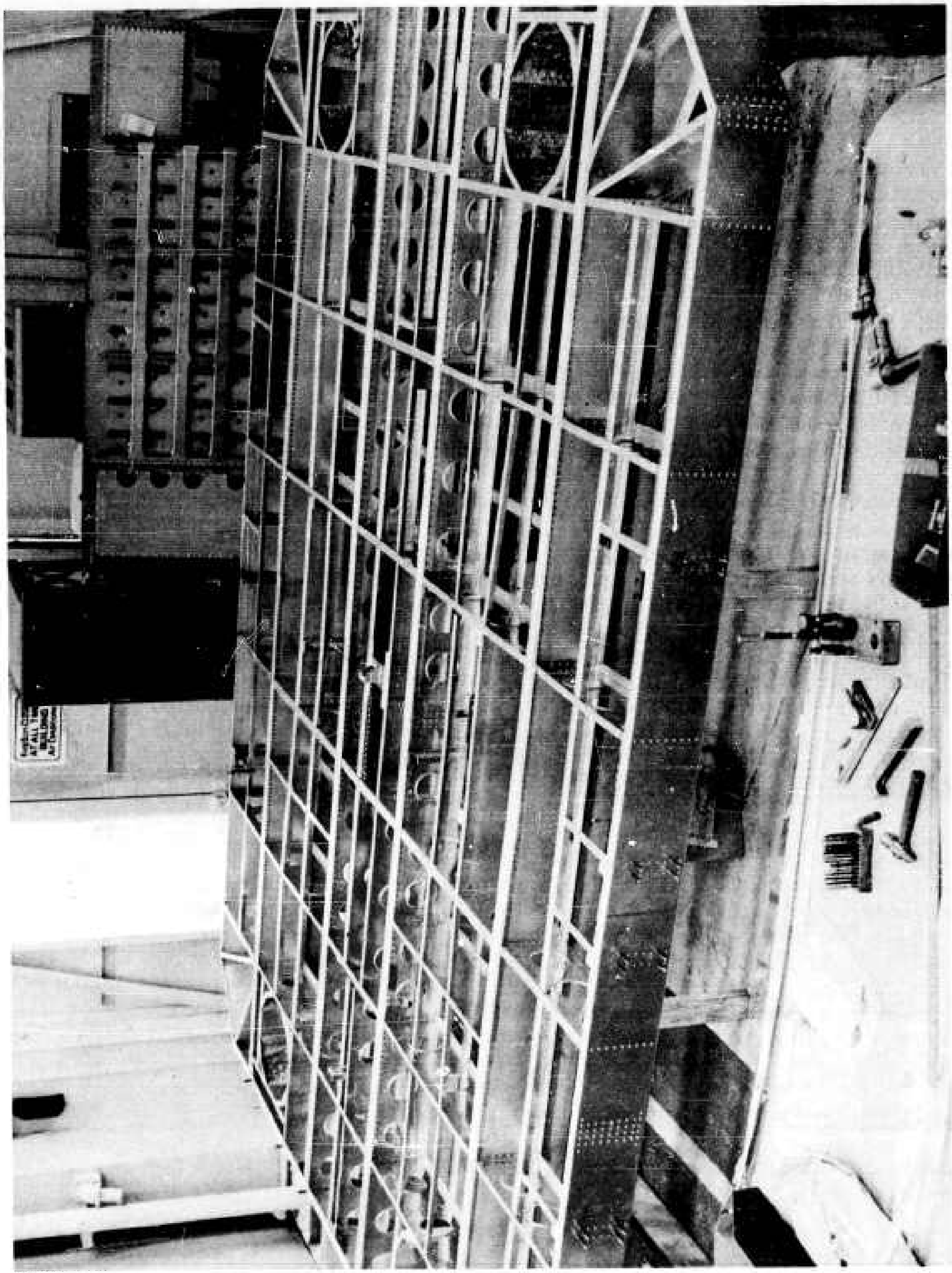


Figure 4. Platform Construction

Simplicity in construction is easily achieved with this type of structure. Six beams extend the length of the vehicle and are spaced laterally at appropriate intervals to accept mounting of engines. Slab type caps are placed over the flanges of the beams in order to provide sufficient material to carry the bending loads in the beam caps. These caps also serve as skin splices in some cases. At the edge of the platform the piano-hinge (for ejector movement) is also used as the beam cap in that area. Depending upon load requirements, the cap thickness varies from .040 to .125 inches. Beam web thickness is .063 inches with flanged lightening holes incorporated for stiffening. Major shear loads and concentrated loads are introduced to the beams either directly by attaching fittings or indirectly as transferred from ribs to the beams. Ribs are also stiffened by flanged lightening holes, as shown in Figure 5, and web thickness varies from .032 to .063 inches depending upon local load requirements. In the corners of the platform the ribs are especially heavily loaded by introduction of landing gear loads and by transverse bending. Ribs are therefore reinforced by nested cap angles or cap strips where necessary.

Conventional round head rivets are used for attaching except in blind areas (the bottom of the platform) where pull-type rivets are used. Panel size is controlled by spacing of angle-type stringers axial to the long dimension of the platform.

3.3.4 Structural Analysis

Sample calculations are subsequently presented to illustrate the type of stress analysis performed in the design of the primary structure. It is noted that typical aircraft techniques were used.

3.4 DESIGN ANALYSIS OF EJECTOR SYSTEM

The design of the recirculating ejector system which provides the lift and control of the MCTV were designed in three phases. The first phase of the design was the analytical and experimental selection of a recirculating ejector geometry which would provide the required performance. The second design phase was the selection of the ejector arrangement on the periphery of the MCTV platform to achieve the desired control and to provide an effective sealing curtain at the corners. The third phase was the design of the ejector structure and hardware to provide the required ejector geometry and structural strength by means of conventional manufacturing methods.

3.4.1 Selection of Ejector Geometry

The basic design criteria which governed the selection of the ejector geometry were as follows:

1. Design hover height ~ 1 foot
2. Base pressure ~ 15 psf
3. Total primary air available ~ 3.7 lb/sec at 34 psig
4. Platform perimeter ~ 52 feet

Figure 5. Typical Platform Rib Construction

The analytical design of the recirculating ejector for the MCTV was accomplished using the methods established in the previous research program and covered in detail in Section 7 of Reference 2. Figure 6 illustrates a typical recirculating ejector and indicates the parameters which govern the analytical design.

The analytical design of the recirculating ejector was accomplished by use of a digital program which provided a simultaneous solution to the flow equations describing the ejector system. Inputs to the program included the primary stagnation pressure, density, and temperature plus the tertiary mass flow and velocity at the end of the ejector mixing section. An empirical correction to account for turn losses was considered after the centerline geometry of the ejector, turn, and exit were established along with the inlet and exit angles. The tertiary exit conditions were established from the height and base pressure and the selection of an exit thickness-to-height ratio (t_e/h) of 0.25. Solutions of the flow equations were obtained for various values of secondary pressure recovery and mixing section static pressure until a solution that matched the available primary mass flow from the power plants was obtained. The required secondary pressure recovery was approximately 50 percent of the tertiary exit pressure. This value was realistic since pressure recovery values greater than 50 percent had been obtained experimentally on other ejector models. The matched solution of the ejector flow equations provided the necessary areas and area ratios. Figure 7 presents the important recirculating ejector dimensions.

The final design of the recirculating ejector geometry to be utilized in the MCTV was established after an experimental program was undertaken to check performance and optimize inlet and primary nozzle header configuration. A full scale two-dimensional model of the ejector was fabricated for testing in the existing two-dimensional test facility. Five inlet shapes and three primary nozzle arrangements were tested. These tests were run using the air from the MCTV power plants to determine the effect of hot (400°F) primary air on ejector component performance. The inlet and nozzles which resulted in the highest performance were incorporated in the final design. The use of flaps at the tertiary exit had proven to be valuable in maximizing base pressure at off-design heights in models tested in previous studies. The incorporation of small flaps at the exit of the ejector completed the geometrical design of the ejector for use on the MCTV.

The two-dimensional model was tested over a range of primary pressure and temperatures and operating heights. The performance of the ejector was sufficient to accomplish the performance objectives of lift and height.

3.4.2 Selection of Ejector Control and Corner Configuration

One of the basic performance objectives to be demonstrated by the MCTV was the utilization of the momentum force produced by the ejector flow for control. The magnitude and direction of the force on the ejector walls resulting from the turning of the internal flow is shown in Figure 8.

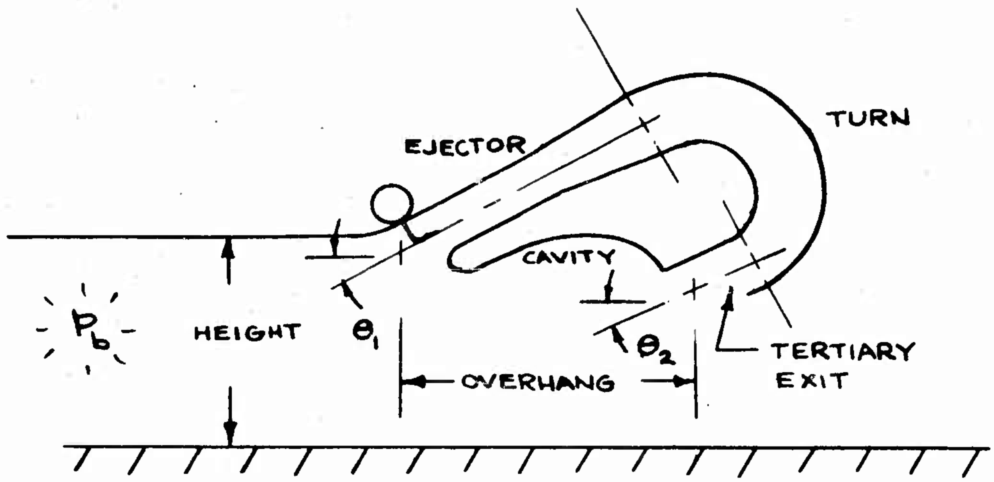


FIGURE 6 RECIRCULATING EJECTOR DESIGN PARAMETERS

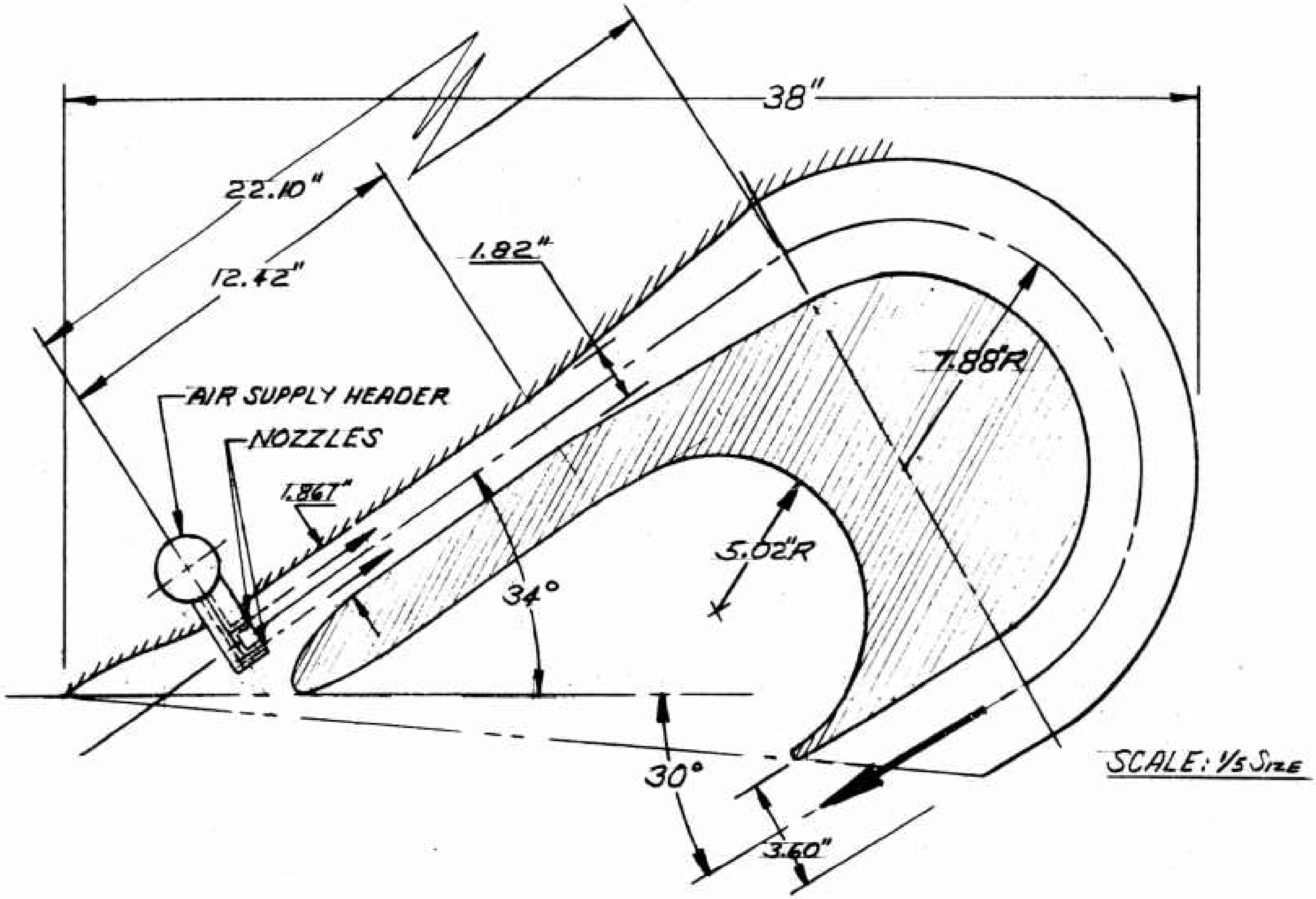


FIGURE 7
BASIC DIMENSIONS OF RECIRCULATING EJECTOR FOR MCTV

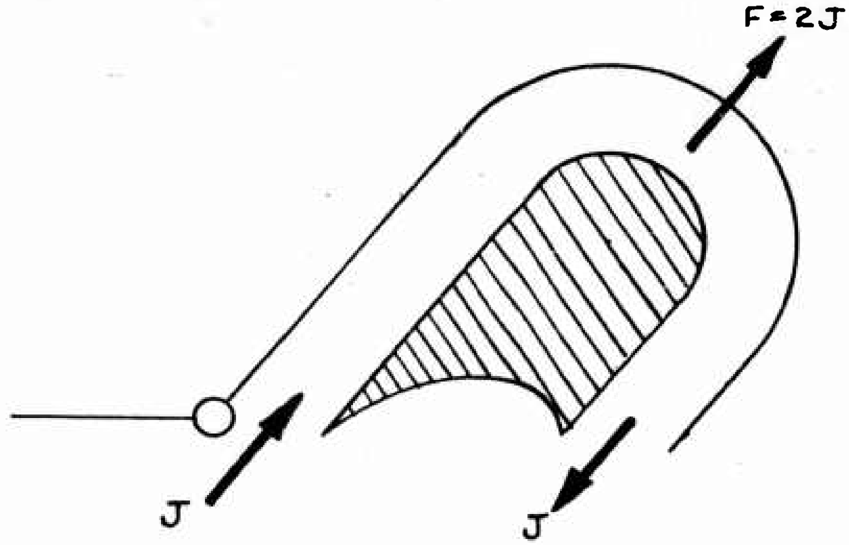


FIGURE 8 EJECTOR CONTROL FORCE

The magnitude of the resultant force is not appreciably affected by the rotation of the ejector around the hinge point. The existence of this force in the ejector and the ability to change the direction of the force by rotation of the ejector comprises the control system utilized on the MCTV. Differential movement of ejector banks around the vehicle periphery produces the moments necessary for pitch, yaw, and roll control.

The selection of an ejector peripheral configuration which would provide the required control functions with minimum complexity was governed by the dimensions of the vehicle platform. The original dimensions of the platform were 8 feet x 15 feet. Control moments of similar magnitude around the three axes were achieved by arranging the ejectors as shown in Figure 9.

Results from tests of the small three-dimensional wind tunnel model (Reference 3) indicated a loss of lift performance resulting from corner leakage. The leakage of the cushion pressure was attributed to the imcomplete curtain at the corner using a configuration similar to that shown in Figure 9. Small scale testing of corner configurations established that an effective curtain seal could be achieved by the configuration shown in Figure 10.

Incorporation of the corner ejector while retaining the same pitch and roll control moments made necessary a redesign of the basic platform. The platform dimensions were therefore changed from 8 feet x 15 feet to 12 feet x 15 feet.

3.4.3 Ejector Structural Design

The recirculating ejector system is of primary importance in achieving lift performance. However, the ejectors are structurally secondary to the base platform. Therefore the main structural consideration in the design of the ejectors was to provide the strength necessary to hold the dimensional tolerances of the ejector geometry. The structural design of the ejectors therefore received considerable attention during the design phase of the program.

Primary considerations in the design of the ejectors were light weight, overall rigidity and local panel stiffness. Panel stiffness was necessary in the region of the mixing section in order to hold critical dimensions under operating pressures down to -50 psf. Each ejector is provided with a stainless steel header which supplies primary air through airfoil nozzle banks spaced at 1.8 inches along the header. These headers are shown in Figure 11.

The ejector structure consists of a closed box beam which forms the aerodynamic configuration for the inner wall and cavity area. The beam acts as a torque box under normal loads and is of semi-monocoque construction with a .125 inch aluminum skin. The outer wall of .020 inch aluminum is constructed on the torque box by means of ribs spaced at approximately 18 inches. The ribs are formed to the aerodynamic shape required in the ejector. Local stiffness to support

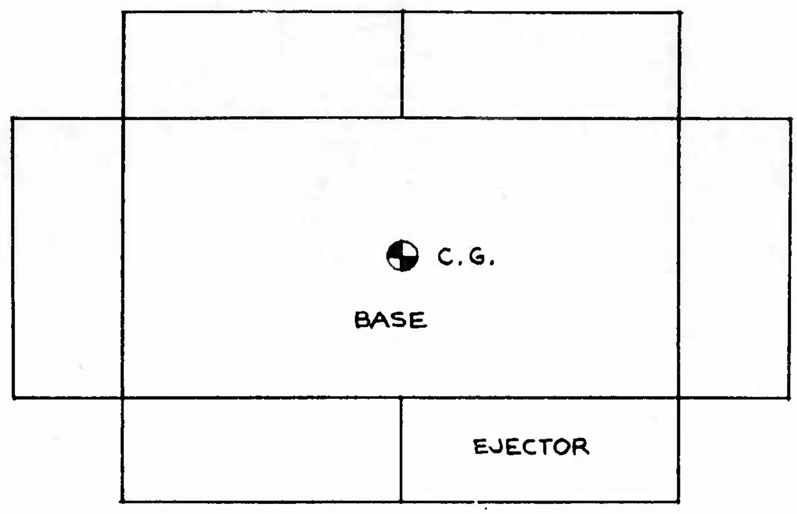


FIGURE 9 EJECTOR BANK CONTROL CONFIGURATION

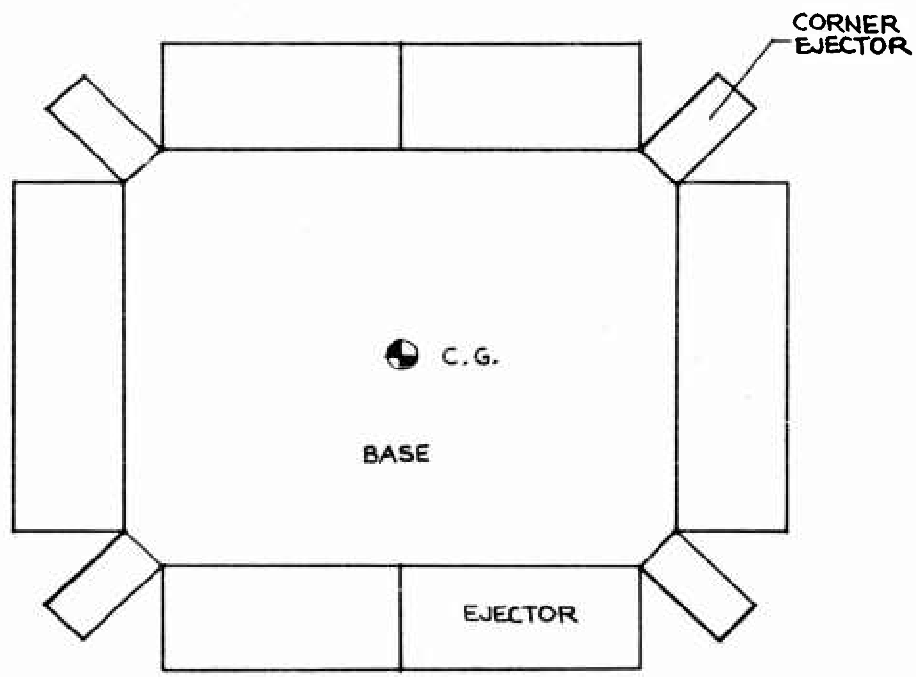


FIGURE 10 CORNER EJECTOR MODIFICATION

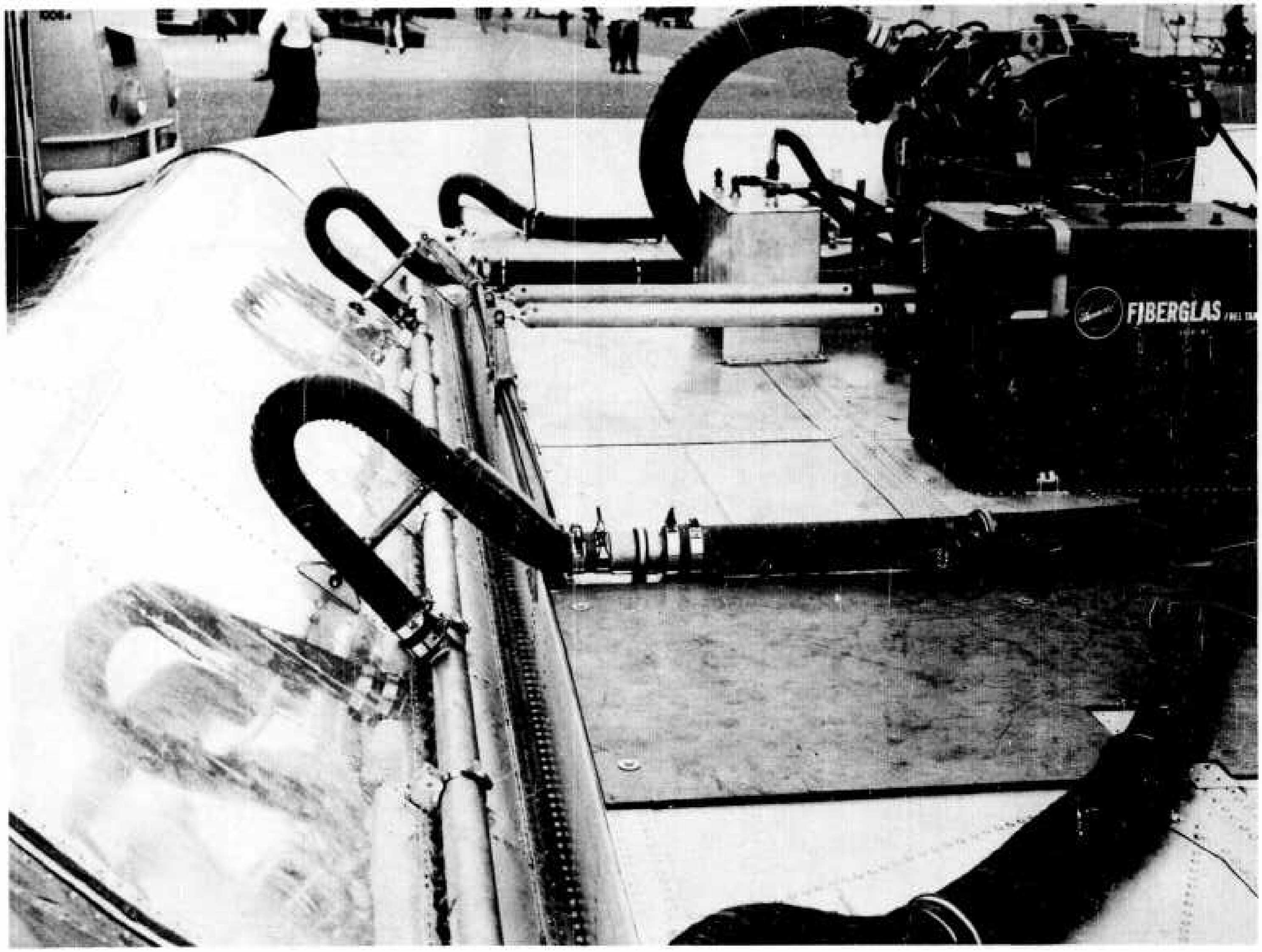


Figure 11. Ejector Nozzle Header Configuration

operating pressure in the mixing area is provided by a sandwich construction utilizing a urethane foam filler. This same sandwich material is used to form the closing ribs at each end of the ejector. In this manner, the required rigidity is transferred to the outside wall since the end plates resist any warpage that would be produced by torsional loads. Figure 12 illustrates the construction methods used on the ejectors and Figure 13 shows the piano hinging used to attach the ejectors to the platform.

3.5 DESIGN ANALYSIS OF DUCT SYSTEM

3.5.1 Design Considerations

The pneumatic ducting system on the MCTV supplies compressor bleed air to the ejector nozzle headers. The design and selection of a suitable ducting system was therefore dictated by the compressor flow and the ejector configuration which had been established.

The ejector configuration as shown in Figure 10 was composed of two 10 foot ejectors for the front and rear, four 6.5 foot ejectors for the side sections, and four 1.4 foot ejectors for the corners. Each ejector was designed for the same amount of primary flow per foot of header length. Although each header required amounts of primary air established by the header length, each header was designed to be fed by a single duct. This design consideration was dictated by the requirement for ejector rotation which necessitated ducting simplicity and flexibility.

Single ducts to each of the 10 ejectors required the design of a plenum to diffuse the flow from each compressor and minimize losses in dividing the flow to the ducts. Each of the distribution ducts from the plenum was required to alleviate all thermal expansion and minimize flow resistance with minimum weight penalty.

3.5.2 Duct System Design and Description

The requirement for low thermal expansion and flexibility at the ejector eliminated steel tubing as ducting. It was determined that ducts made of 2-ply neoprene on fiberglass action-flex tubing would alleviate thermal expansion effects, provide thermal insulation to resist cooling of the air within the ducts and have low weight and low cost. This type of ducting was selected for the ducts connecting the plenum and the headers and also for the larger ducts feeding the plenum from the two compressor outlets. Preformed elbows were designed to provide the required flexibility at the ejector hinge.

To simplify the design and minimize costs, all ducting connecting the plenum and headers was designed with the same internal diameter. Sizing of the ducts was established by determining the duct diameter required to maintain low flow velocities in the feed duct with the highest flow. Ducting to the corner ejector is therefore about twice the required diameter. The ducting system and plenum are illustrated in Figure 14.

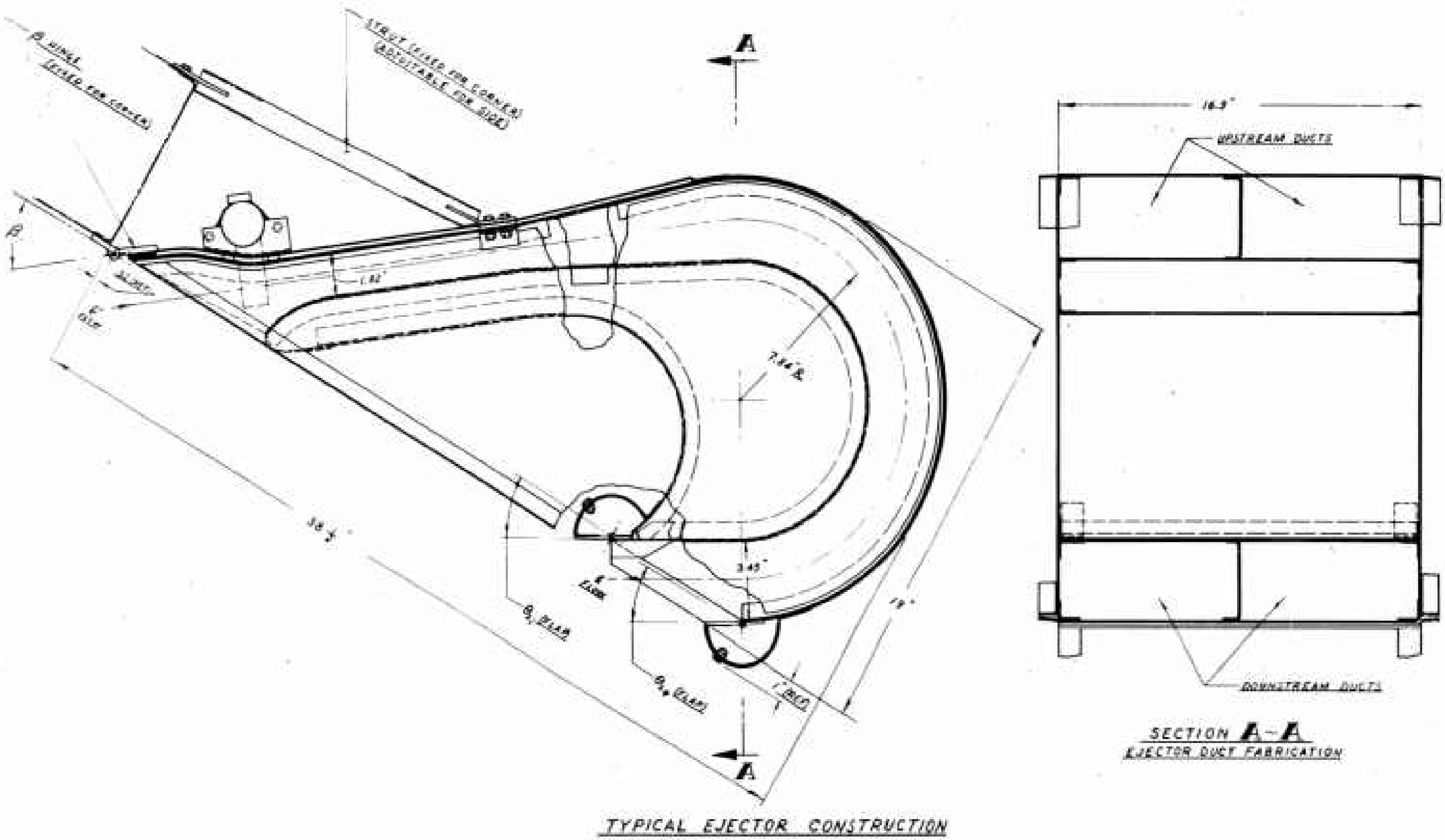


Figure 12. Ejector Fabrication Drawing.

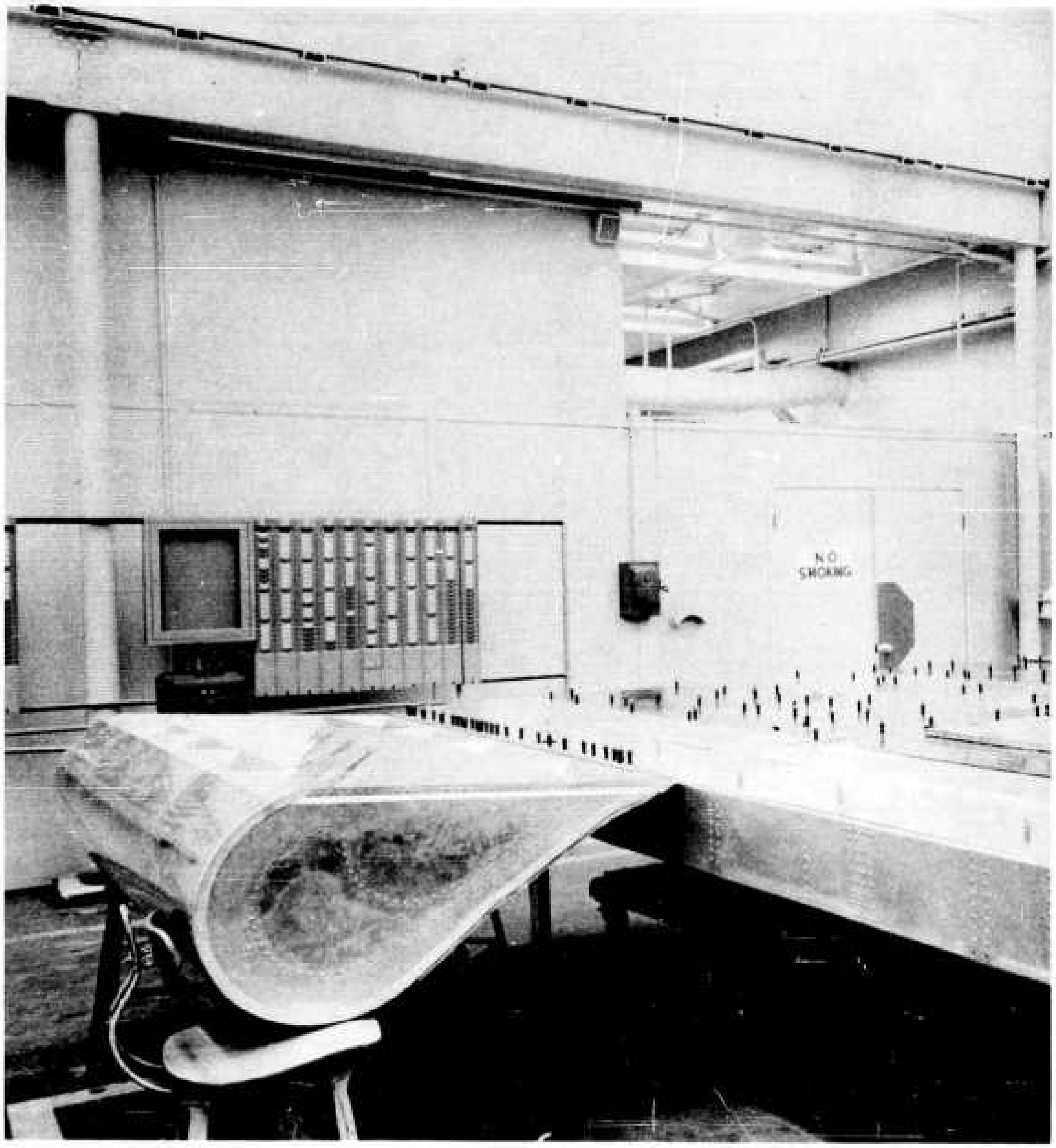


Figure 13. Method of Ejector Hinging to Platform

Figure 14. Primary Air Feed System

3.5.3 Duct Loss Analysis

An analysis was made of the ducting system to determine anticipated losses in the temperature and pressure of the air feeding the headers. The following assumptions were made in order to evaluate the duct design:

1. Air leaves the compressors at 50 psia and 430°F
2. Each compressor delivers 108 lb/min

Figure 15 shows the estimated effect of the ducting on the total pressure of the primary air as it flows from the compressor to each primary nozzle of the ejector system. In order to gain the advantages of light weight, thermal insulation and low thermal expansion of the fiberglass flex-tubing a penalty in friction factor due to surface roughness was incurred. Friction factors were estimated to be twice that of smooth metal tubing. Consequently, the pressure drop for this ducting is twice that experienced in stainless steel ducting of the same configuration; however, this amounts to only a 5 percent loss in total pressure between compressor and headers.

It is noted in Figure 15 that there is some difference in the estimated pressure drop in the ducting connecting each compressor to the plenum. This is best explained by examination of Figures 14 and 16 which show that duct 9 is twice as long as duct 10 and has a correspondingly greater pressure loss. (Ducts 9 and 10 have the same diameter.) The plenum will equalize the total pressure from each supply duct to the lower value and duct 9 will have a slightly lower flow than duct 10.

3.5.4 Duct System Component Testing

During the experimental verification of the MCTV ejector two-dimensional performance, the fiberglass flex-tubing was also tested to ensure its ability to withstand the temperatures and pressures of the primary air supplied by the compressors. Measurements made during check-out runs of the complete MCTV engine-duct installation showed a negligible pressure loss in the system indicating that the preceding duct-loss analysis is conservative.

3.6 DESIGN ANALYSIS OF CONTROL SYSTEM

The forces produced on the recirculating ejector walls by turning the flow through approximately 180° offer an effective means of control for a recirculation GEM. Hinging of the ejector banks on the periphery of the platform as described in Section 3.3.2 establish the basis for the design of the control system.

Deflection of the hinged ejectors is achieved by a conventional aircraft-type control system which provides complete manual control by the operator. The ejectors are linked by a series of pushrods and torque-tubes and are manipulated by a control stick and a "rudder bar" foot mechanism. Control stick operation is the same as for conventional aircraft. Fore and aft motion of the stick

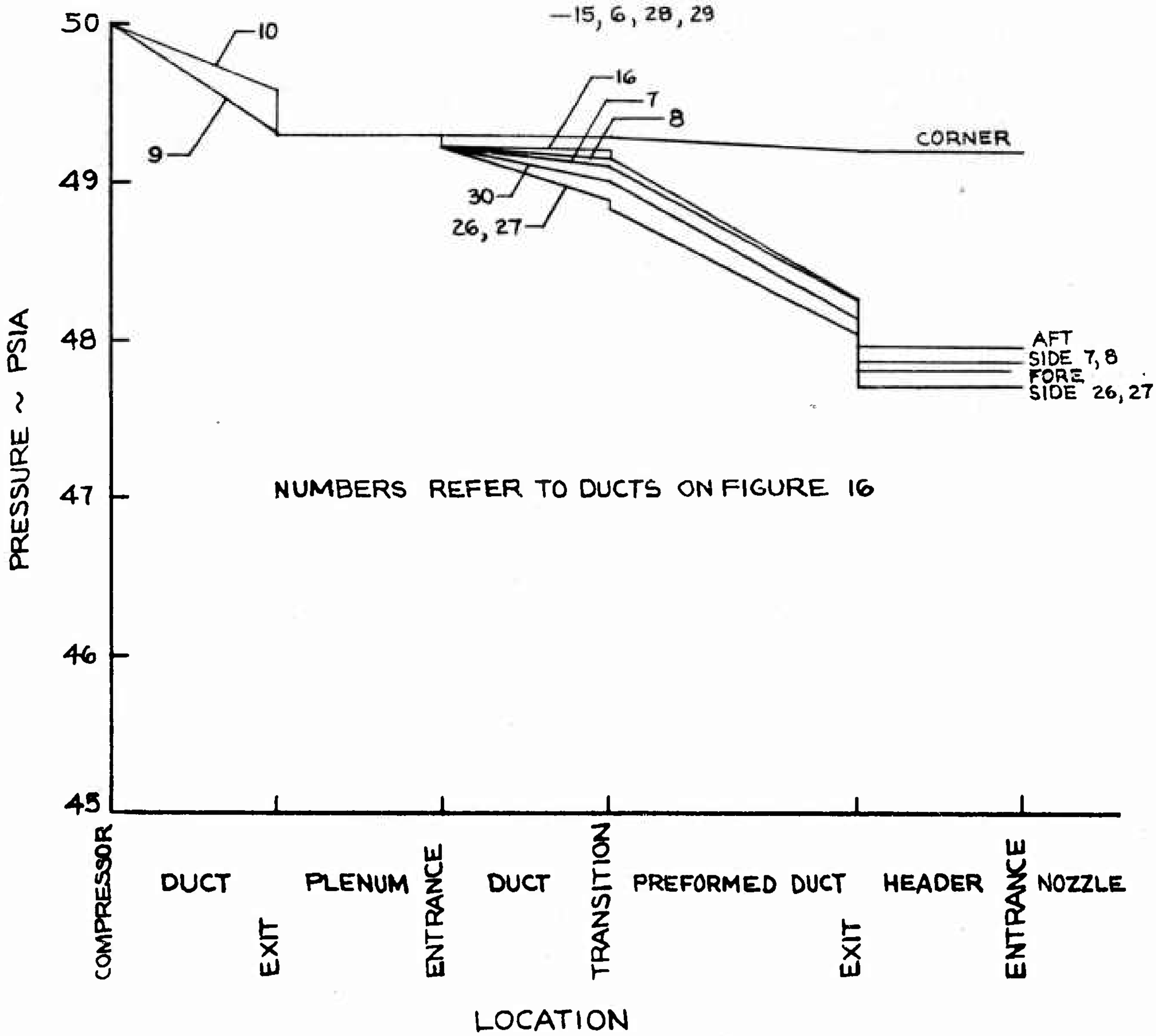


FIGURE 15 PRIMARY AIR FEED SYSTEM PRESSURE LOSS

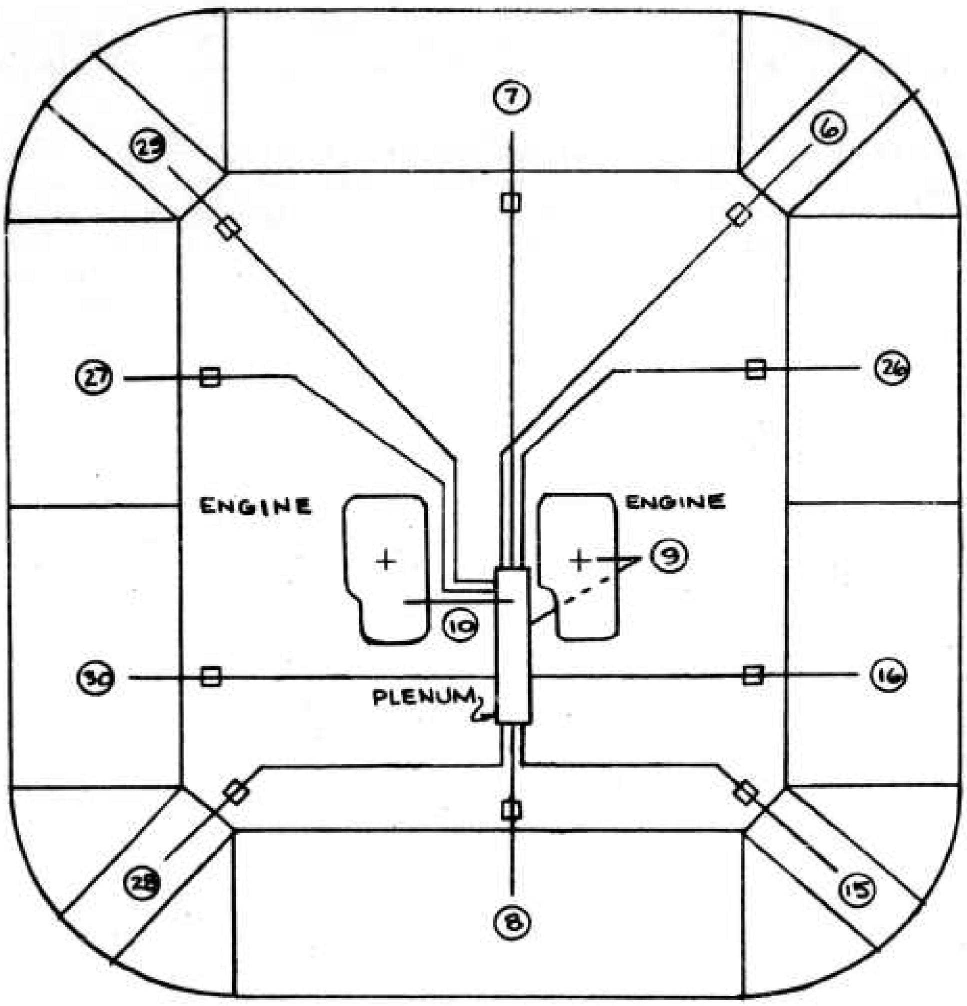


FIGURE 16 PRIMARY AIR FEED SYSTEM SCHEMATIC

deflects the front and rear ejectors to produce a pitching moment. Lateral motion of the stick deflects the side ejectors in unison to produce a rolling moment. Movement of the "rudder bar" causes differential motion of the side ejectors to produce a yawing moment.

Each ejector can be rotated through a range of 10° up and 10° down around the hinge point. The side ejectors can be rotated through an additional 10° up and 10° down for yaw control. A vernier adjustment of plus or minus 10° is incorporated in each pushrod to provide for increased or decreased ejector deflection if required. The controls may be locked for operation with the ejectors in the neutral position. The control system is illustrated in Figure 17.

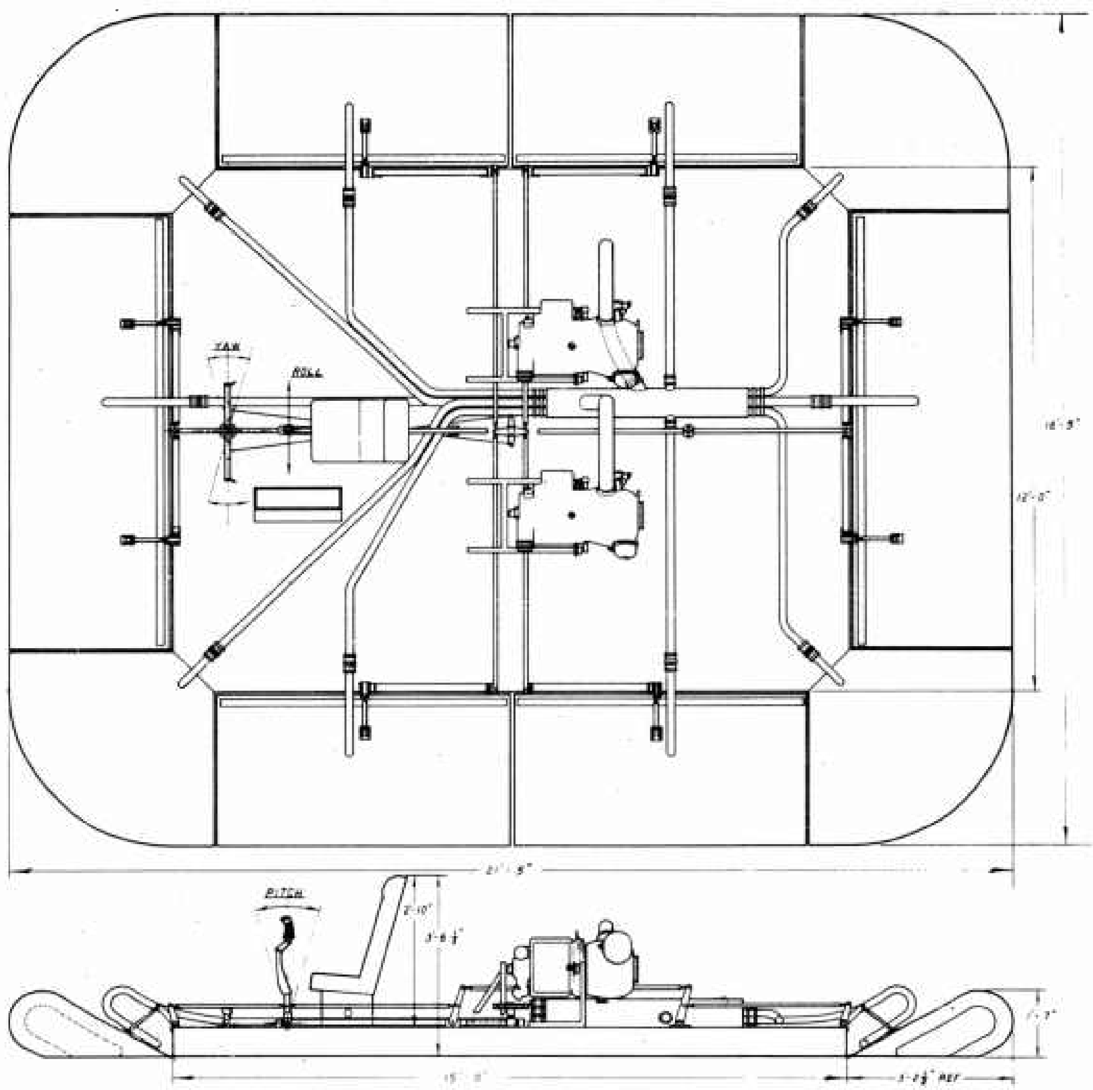
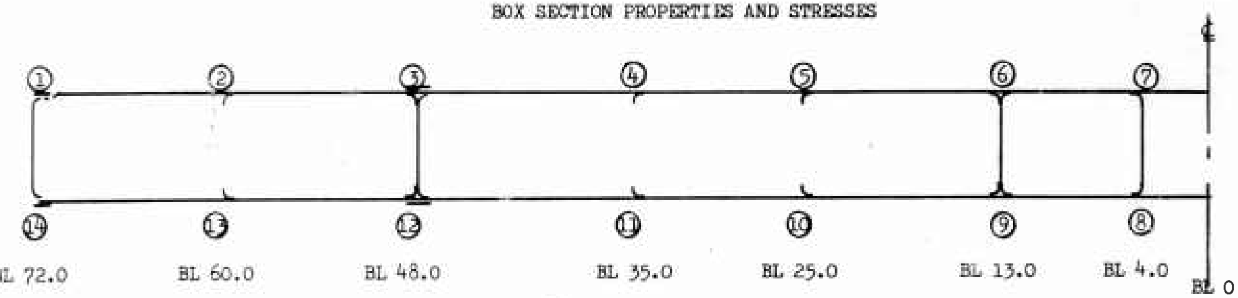


Figure 17. MCTV Assembly and Control System Drawing.

STRESS ANALYSIS

BOX SECTION PROPERTIES AND STRESSES



Item	Area	y	Ay	Ay^2	I_o	$\bar{y}$	$\bar{y}/I$	f_b(psi)	P(lb)
1	.27263	3.80508	1.03738	7.92282	.01130	4.93341	.06010	7,630	2,090
2	.12572	3.92770	.49379	1.93946	.01162	5.05603	.06160	7,820	983
3	.54730	3.81288	2.08679	7.95668	.03926	4.94121	.06020	7,640	4,190
4	.10672	3.91651	.41800	1.63710	.00954	5.04484	.06146	7,800	834
5	.14872	3.93720	.58554	2.30539	.01385	5.06553	.06171	7,650	1,170
6	.73260	3.77798	2.76775	10.45650	.07254	4.90631	.05977	7,600	5,580
7	.12572	3.92770	.49379	1.93946	.01163	5.05603	.06160	7,820	980
8	.37500	-3.78063	-1.41774	5.36000	.01577	-2.65230	-.03231	-4,100	-1,540
9	.71600	-3.78378	-2.70919	10.25098	.07097	-2.65545	-.03235	-4,110	-2,940
10	.47000	-3.77232	-1.77300	6.68832	.01977	-2.64399	-.03221	-4,090	-1,920
11	.44400	-3.75964	-1.66928	6.27589	.01300	-2.63131	-.03206	-4,070	-1,810
12	.72400	-3.75561	-2.71906	10.21173	.03654	-2.62728	-.03201	-4,060	-2,940
13	.47900	-3.76271	-1.80234	6.78168	.01627	-2.63438	-.03209	-4,080	-1,950
14	.63273	-3.87184	-2.44983	9.48535	.04107	-2.74351	-.03342	-4,240	-2,680
	5.90014		-6.65730	89.21136	.38313				

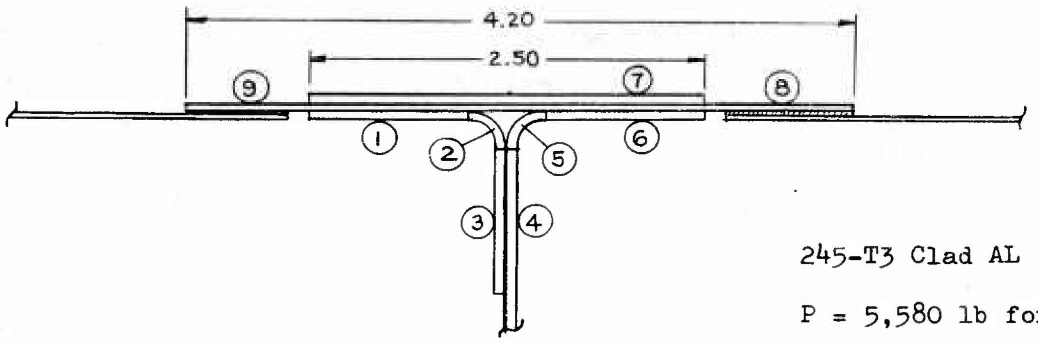
$$\bar{y} = \frac{-6.65730}{5.90014} = -1.12833$$

$$I = -\ 1.2833\ (6.65730) + 89.21136 + .38313 = 82.08286$$

$M_{MAX} = 6\ M_{1g} = 6\ (42,300) = 254,000$ in-lb for full cross section

Sample Cap Analysis

Element 6, BL 13.0 cap (from previous page)



245-T3 Clad AL

P = 5,580 lb for BL 13.0 cap

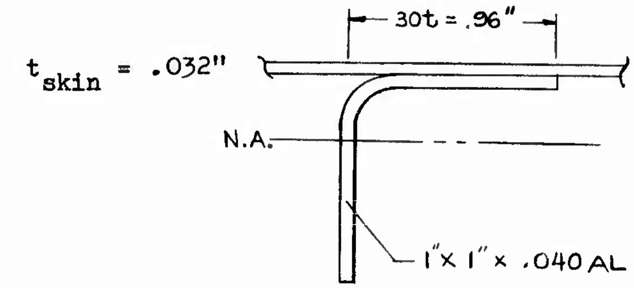
Item	t	b or R	A	b/t or R/t	Fcc (Ksi)	Pcc (lb)
1	.063	1.00	.063	15.9	15.5	975
2	.063	.209	.021	3.32	47.8	926
3	.063	1.00	.063	15.9	15.5	975
4	.063	1.00	.063	15.9	15.5	975
5	.063	.209	.021	3.32	47.8	926
6	.063	1.00	.063	15.9	15.5	975
7	.103	2.50	.258	24.3	11.2	2,880
8	.040	.85	.034	21.3	12.5	425
9	.040	.85	.034	21.3	12.5	425
			.620			9,480

$$(Fcc)_{AV} = \frac{9,480}{.620} = 15.3 \text{ ksi}$$

$$M.S. = \frac{Pcc}{P} - 1 = \frac{9,480}{5,580} - = \underline{\underline{+.70}}$$

Sample Column Analysis

Element (4), BL 35.0



$I_{NA} = .00954$

$A = .10672$

$\rho = \sqrt{I/A} = \sqrt{.00954/.10672} = .300$

In area where maximum cap load occurs, the bay length between ribs is 33 inches. An effective length for column action is obtained by assuming end fixity of c = 1.5.

$L' = L/\sqrt{c} = 33/\sqrt{1.5} = 27.0$

$L'/\rho = 27/.300 = 90$

From Euler's column formula, $F_{col} = \dfrac{\pi^2 E'}{(L'/\rho)^2} = 12{,}100$ psi

$f = 7{,}800$ psi for element (4) BL 35.0

$$M.S. = \frac{F_{col}}{f} - 1 = \frac{12{,}100}{7{,}800} - 1 = \underline{\underline{+.55}}$$

TABLE 1

TABLE OF PROPULSION SYSTEMS

	Ambient Temp. °F	Height: Weight 3000#	Height: Weight 2500#	m' lb/sec	Absolute Pressure (p_0') a	HP'	Lift @12"	Lift HP @12"	Gross Weight	P_b
I. Present Configuration										
a) Present engines	90	-	-	3.7	48	270	1800	6.7	2440	8.0
b) New engines, nozzles reamed to maximum										
1. At present horsepower (approximately)	90	-	10	4.8	41	307	2280	7.4	-	10.1
2. Fifty percent increase in horsepower	90	10	16	5.6	46	406	2840	7.0	-	12.6
3. One hundred percent increase in horsepower	90	15	18	6.5	50	494	3320	6.7	-	14.8
c) New engines, new header and nozzles	90	12	17	10.0	25	260	3000	11.6	-	13.8
d) Requirement for base pressure of 40 psf	90	Not applicable		30.8	25	800	9000	11.3	-	40.0
II. New Engines										
a) Two, GTC-85-24	60	-	8	3.86	54	325	2100	6.45	2440	9.4
	90	-	6	3.50	52	290	1880	6.48	2440	8.55
b) Two, GTC-85-24 plus One, GTC-100-1	60	14	17.5	5.77	54	487	3180	6.54	2790	14.15
	90	11	15.4	5.25	52	440	2920	6.64	2790	13.0
c) Two, GTC-100-52	60	Not applicable		6.67	76	860	5050	5.88	2640	22.5
	90	21	24	5.92	72.5	694	4100	5.90	2640	18.3
d) Two, GTC-85-28	60	-	10.5	4.4	54	365	2370	6.49	2310	10.6
	90	-	8	3.74	52	310	2000	6.45	2310	9.15
e) Three, GTC-85-28	60	18	21.5	6.6	54	547	3600	6.58	2550	15.9
	90	14.5	18	5.61	52	491	3250	6.62	2550	14.5
f) Two, GTC-85-28 plus One, GTC-100-1	60	15.5	19.5	6.31	54	527	3450	6.55	2650	15.3
	90	13.5	17.5	5.49	52	472	3150	6.68	2650	13.95
g) Two, Continental 141 or Two, New Palouste IV	60	-	10.5	4.4	52	360	2370	6.58	2310	10.6
	90	-	7.5	4.2	50	300	1970	6.56	2310	8.95
h) One Fiat - 4700.000	60	19.8	23.0	7.0	63	550	3750	6.82	2400	16.7

4.0 DESCRIPTION OF MAN CARRYING TEST VEHICLE

The overall configuration of the MCTV is illustrated in Figure 17. This drawing presents the location of all the sub-systems and components which comprise the test bed. The vehicle is approximately 19 feet wide and 22 feet long. At a hover height of 12 inches, the clearance height of the vehicle is 5 feet (to the top of the operator's head). Figure 18 shows the completed MCTV.

4.1 WEIGHT BREAKDOWN AND BALANCE

A basic performance criterion established for the MCTV design required a gross weight-to-lift horsepower ratio of 8 to 10. The selection of two AiResearch GTC-85 turbo-compressors as the primary powerplant set the pneumatic horsepower for lift to be approximately 290 horsepower. The preliminary design gross weight of 2500 lb resulted from the selection of these engines.

The design of each major and minor system which comprise the total MCTV configuration was closely controlled by the weight requirements. Weight estimates were made during each design phase and certain systems required close design attention to maintain the gross weight below the nominal weight requirements.

A second design consideration which affected the overall design of the MCTV was the requirement of static balance to insure a level attitude in hover. The location of each component was determined initially to produce static balance. A number of major components were designed with the flexibility of limited movement for balancing. Balance was simplified by the symmetry of the configuration laterally and provisions for longitudinal balance changes were incorporated primarily.

The final weight estimate prior to actual completion of the MCTV was 2564 lb. Table 2 shows the weight estimates of the components which make up the total weight of the vehicle.

After completion of the vehicle, the gross weight was measured by suspending the vehicle from a sling coupled to a load cell. The gross weight including pilot and full fuel load was determined to be 2430 lb. The static balance of the vehicle proved to be quite close and only minor adjustments were required to balance it completely.

4.2 DESCRIPTION OF SECONDARY SYSTEMS

4.2.1 Fuel System

The fuel system for the MCTV was chosen after the fuel requirements of the engine and the fuel weight limitations were established. Two lightweight fiberglass 20 gallon tanks were mounted forward of each engine and secured to the platform by straps as shown in Figure 19. Standard flexible hose was installed to couple the tanks to the fuel pump and turbine combustion section.

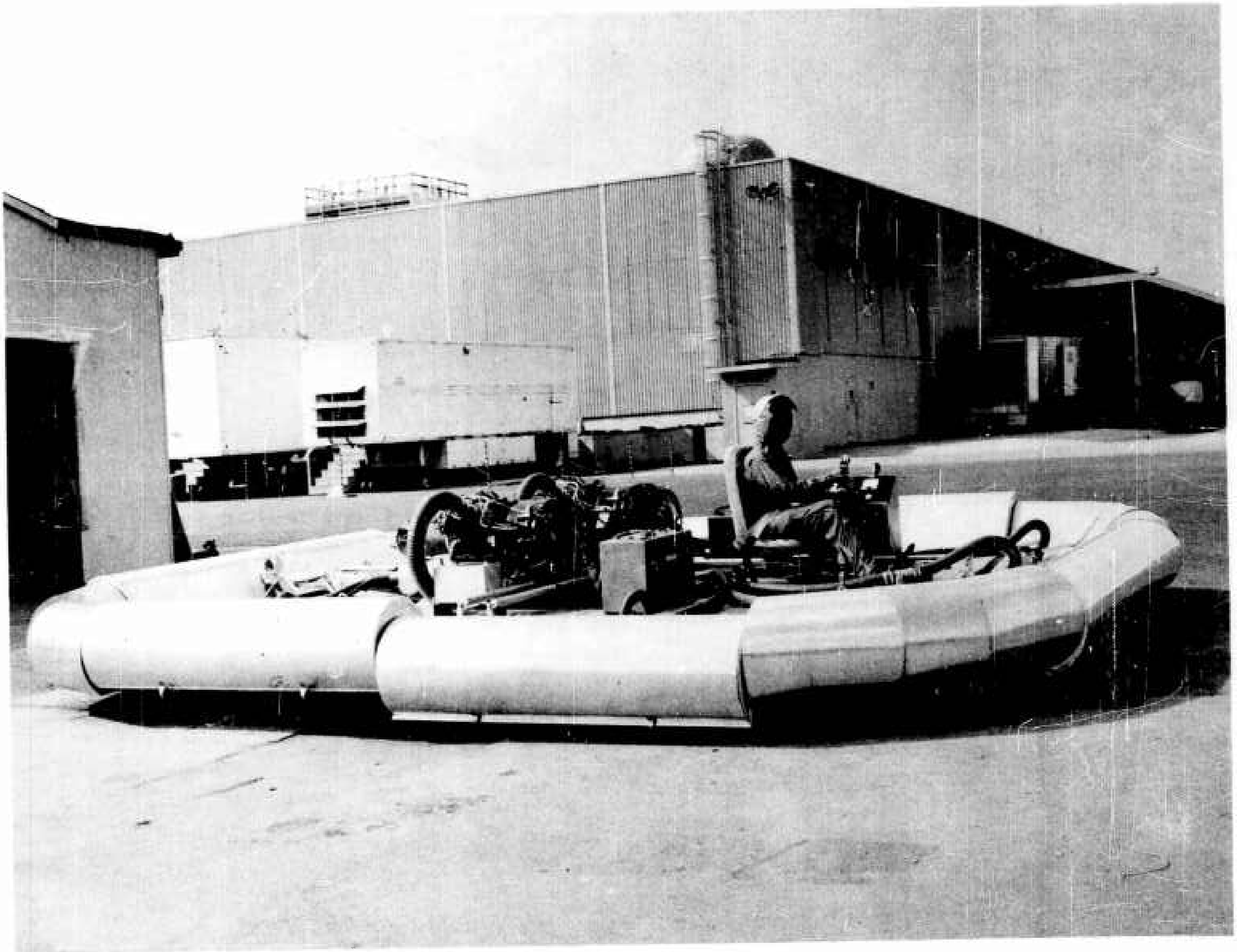


Figure 18. Completed Man Carrying Test Vehicle

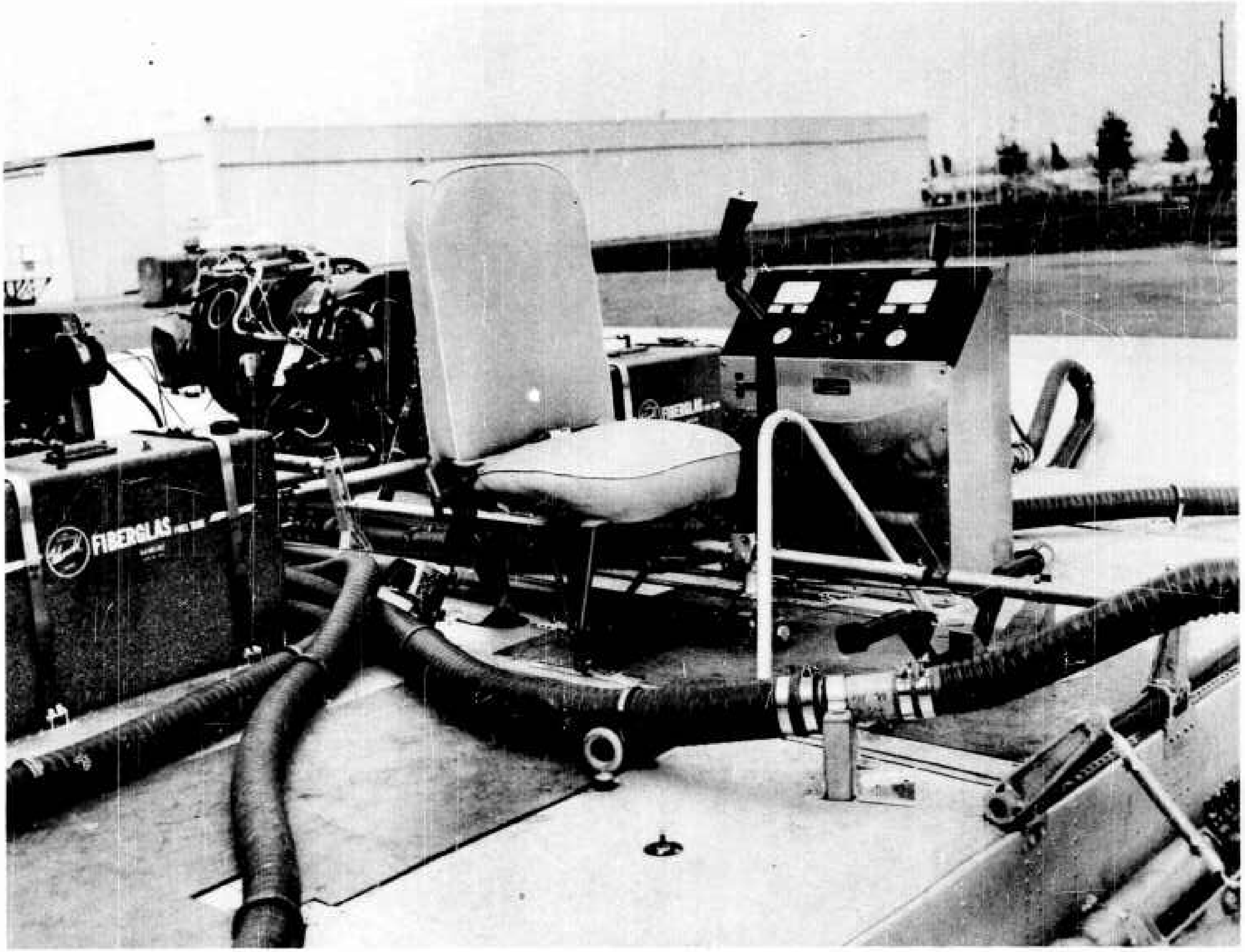


Figure 19. Fuel System, Instrument Console, and Operator Seat

4.2.2 Instrument Console

The instrumentation and powerplant controls were limited to the minimum requirements of the powerplants. Switches for each engine were provided for start, ignition on, ignition off, bleed on and bleed off. Instruments for each engine included a tachometer and an exhaust temperature meter. The total pressure in the plenum was monitored with a Bourdon gage. All instruments and switches were mounted in a console located at the operators left, as shown in Figure 19. Bourdon gages were mounted on the compressor section of each engine for monitoring compressor bleed pressures.

4.2.3 Operators Seat

The operators seat is of the type used in small private aircraft. The seat is mounted on a framework fabricated of welded aluminum tubing. The seat bolts to a roller-rail mounting which allows adjustment of the seat for operator comfort. Seat belts are provided for maximum operator safety. The seat is shown in Figure 19.

TABLE 2

MCTV COMPONENT WEIGHT SUMMARY

	Weight ~ lb.
Structure	(1172)
Base (12' x 15')	524
Ejectors	508
Corner Ejectors	140
Engine Installation	(596)
Compressors (2) GTC 85-24	450
Mounts	45
Exhaust	25
Intake	32
Oil System	5
Fuel System	39
Primary Air Ducting	137
Control System	98
Instrument Group	(24)
Instrument and Panel	14
Instrumentation	10
Electrical System	17
Pilot Accommodations	20
Landing Gear	44
Weight Empty	2108
Useful Load	(456)
Pilot	175
Oil (3 gal)	21
Fuel 40 Gal (JP-4)	260
Gross Weight	2564

5.0 REFERENCES

1. Martin OR 1275, "Recirculation as a GEM Lift System," October 1960

2. Martin OR 2073, "Recirculation Principle For Ground Effects Machines - Two Dimensional Tests", May 1962

3. Martin OR 2497, "Recirculation Principle For Ground Effects Machines - Three Dimensional Wind Tunnel Tests", May 1962

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Martin Company, Orlando Division, Orlando, Fla., RECIRCULATION PRINCIPLE FOR GROUND EFFECT MACHINES MAN-CARRYING TEST VEHICLE AND COMPONENT TESTING, J. Butsko, R.Reiland, B. Robinson, and C.Middlebrooks, Report No. OR 2498, TCREC Technical Rept 62-99, February 1963, 42 pp. Incl. illus. and tables, (Contract DA 44-177-TC-710) Task 9R99-01-005-04.

Unclassified Report

Design and construction details of an experimental air cushion vehicle using the recirculation principle are

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2. Structures

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